Report on Utilization of the Recycler as a Proton Accumulator

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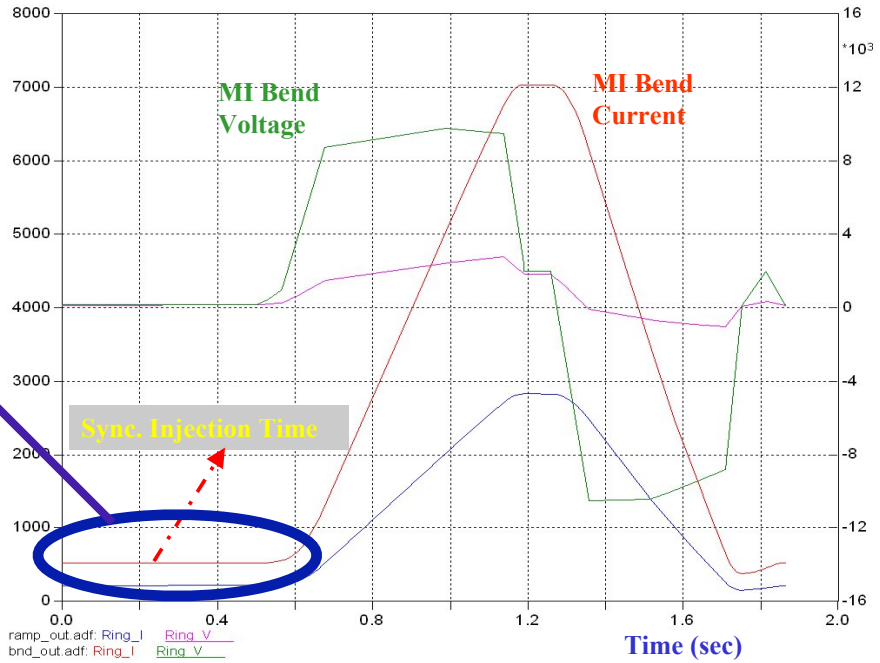
Proton Study Group

First Option -- Recycler

- First foreseen option would be to use Recycler Ring as proton accumulator during Main Injector ramp
  - Main Injector fill time could be reduced from ~0.7 sec to ~10 msec. Cycle time thus reduced from ~2.2 to ~1.5 sec
    - thus, ~50% increase in protons/sec to target

From August PMG

6 Booster Injections



Courtesy I. Kourbanis

Recycler Option

- Appears to need only minor modifications to existing facility
  - Short beam line connecting MI-8 line to RR
  - Probable upgrades to RR rf system

From August PMG

- Questions:
  - Can RR handle higher intensity? Presently, ~2-3x10^{12}; needs ~x20 more for neutrino program
    - beam cleaning, stacking studies -- ~1.5x10^{13} p's used
  - What would be stacking procedure?
    - 53 MHz transfer? Barrier Bucket stacking? …
  - Beam studies and calculations will be suggested to help answer …

Present Status

- Group has been 'on hold' past few months due to
  - Electron Cooling commissioning, PAC, Proton Plan Reviews, pbar Rapid Response effort, summers vacations, Linear Collider organization, Snowmass, etc.
- Negotiated plan w/ AD Head:
  - Originally wanted report in early summer …
  - … will issue a report in Fall concerning RR issues
  - re-evaluate at that point, re-direct from there
- Group should continue to meet; likely to expand and look into further details of likely scenarios
  - looking for first report ~October
  - needs 'jump start' to get going again

From August PMG

Draft Report

- Syphers, Prebys, and Nagaitsev have put together a draft report
- Latest Version:

FIRST REPORT OF THE PROTON STUDY GROUP

Recycling the Recycler

DRAFT – 12/16/05 – DRAFT

I. Introduction

An extended neutrino program is expected to be a core ingredient of the Fermilab program through the first half of the next decade. Elements of this program will likely include an extension of the present MINOS experiment and the Nova off-axis experiment, both using the NuMI beamline. The beam delivered to NuMI will be increased over the next few years through upgrades under the present Proton Plan, which is expected to be completed in 2008. The main elements of this plan aim at the reduction in Booster losses (and thus higher proton throughput in the Booster), a reduction in losses in the Main Injector, the development of slip-stacking or barrier-bucket stacking in the MI, and an upgrade in the MI RF system. The goal for NuMI with these upgrades is an average targeting rate in excess of 44×10^{12} protons (44 Tp) every 2.2 seconds.

The cancellation of the BTeV experiment opens other avenues for further increase in proton delivery to the neutrino program once the Tevatron collider program is terminated. While the ultimate program might be a high intensity Proton Driver facility, it is realistic that such an accelerator, if it were approved, may not be ready for operation at Fermilab by the end of this decade when the LHC is expected to become operational. Thus, viable concepts for upgrading and restructuring the Fermilab accelerator complex to maximize delivery to the NuMI beam line after the end of Run II need to be explored. The Proton Study Group was formed by the Accelerator Division Head to look at options and consider next steps following the conclusion of Run II, as well as the successful completion of the Proton Plan. The current Proton Plan[1] contains upgrades to the Booster and Main Injector to provide 44 Tp every 2.2 seconds from the Main Injector at 120 GeV, corresponding to an average beam power of 400 kW.[2] The scheduled completion date of this plan is in 2008.

[1] *The Proton Plan*, Beams-doc-1441 (2004) .
[2] For scaling purposes, note that 100 Tp every 2 sec at 120 GeV corresponds to 1 MW.

Report Outline

- I. Introduction
  - A Staged Approach
  - Physics Considerations
  - Tevatron Fixed Target
- II. Possible Modifications to Existing Facilities
  - Comments on Existing Proton Source
  - Stacking Protons in the Recycler
    - Overview, RF Requirements
    - Recycler Upgrades, Beam Line Modifications
  - Radiological Issues
- III. Impacts on Experimental Programs
- IV. Summary

Proton Throughput

	Present Operation	Proton Plan	Recycler Option 0	Recycler Option 1	Recycler Option 2	
Booster Limits						
$\langle N \rangle$	4.5	5	5	5	5	Tp/batch
$\langle R \rangle$	5	8	8	8	14	Hz
$\langle NR \rangle$	8	14	14	14	20	10^{16} pph
NuMI Operation						
# batches, B	5	9	9	12	12	
$B\langle N \rangle$	23	45	45	60	60	Tp/cycle
$\langle T \rangle$	2.2	2.2	1.5	1.5	1.0	sec
$B\langle N/T \rangle$	4	7	11	14	20	10^{16} pph
$\langle P \rangle$	200	400	580	770	1000	kW

Table 1 – Proton Throughput. In the case of the first four scenarios, the "*Booster Limits*" represent the output limit of the Booster, as projected in the Proton Plan. In Option 2, the "*Booster Limits*" represent the minimum performance necessary to accommodate the capacity of the Recycler/Main Injector. Option 0 uses a shorter cycle time, but no increase in MI intensity beyond the Proton Plan. In Option 1, 12 Booster batches are used and in Option 2, the MI cycle time has been reduced to 1.0 sec. For both, it is assumed that required MI upgrades to allow higher intensities have been performed.

(very) Rough Cost Estimate

	K$
53 MHz RF system	300
MI-8 mods.	2000
RR/MI xfer mods.	500
RR BPM upgrade	1300
RR BLM upgrade	1000
RR dampers	500
RR LLRF upgrade	200
RR kicker upgrade	400
RR abort mods.	200
RR collimators	500
TOTAL:	6900

Table 2 – *Extremely* Approximate Cost for Recycler Option.

(***needs further input from Sergei***)

The Last Page …

Final Recommendations

Using the Recycler Ring as a pre-injector for the Main Injector synchrotron is the most natural first step toward higher power, at lowest cost, for the Fermilab neutrino program following the conclusion of the Tevatron Collider Run II. With minor changes to the existing infrastructure the proton throughput to the 120 GeV neutrino program can be increased by nearly a factor of two. This is achieved by shortening the cycle time of the Main Injector, as charge is pre-injected into the Recycler Ring from the Booster, and by making available 12 Booster batches to the program once antiproton production is ceased.

To prepare for such an upgrade to take place by the end of the Collider run, expected to occur around 2009, a team should be assembled soon to generate a design document with detailed specifications for the items and modifications required, including the components listed in Table 2 above, including a detailed cost estimate.

The studies discussed in Section IV need to be carried out soon in order to provide input into the design effort. (*delete*??)

Using the Recycler Ring for accumulating 9 Booster batches places no new demands on the Main Injector above those anticipated for the present Proton Plan. The full reach of the Recycler option, using 12 Booster batches would deliver approximately 33% more particles per pulse and the MI will need to be able to handle the new beam intensities and conditions. With this in mind, it is also recommended that a Main Injector upgrade program be further developed and reviewed internally on the earliest possible time scale.

Finally, should the community wish to further investigate the use of the Tevatron as a fixed target program stretcher ring, then a short study should be performed to ascertain the extent of accelerator systems modifications that would be required, and to estimate operating costs for such a program.

Summary

- We see no major issues with Recycler precluding its use as a proton accumulator
  - requires RF upgrades, for 53 MHz
  - plus other upgrades to BPM, dampers, kicker, etc.
  - beam line modifications, but no new civil construction foreseen
  - all modifications are straightforward
  - low-impedance accelerator, should be able to handle proton throughput at 8 GeV
- Main Injector needs to "keep up" with increased intensity
  - can potentially get to ~0.7 MW at 60 Tp per cycle
  - 1 sec cycle --> ~1 MW